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ORIGINAL RESEARCH

CORE STABILITY MUSCLE ACTIVITY DURING STANDING LOWER BODY TWISTING EXERCISES

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ABSTRACT

***Background*:** Little is known about the activity of the abdominal internal oblique (IO) and lumbar multifidus (LM) muscles relative to kinetic chain exercises performed in a standing position.

Hypothesis/Purpose: The purpose of this study was to identify the activity of the IO and the LM muscles during weight-bearing exercises. The authors hypothesized that IO and LM muscle activity would vary with lower body positions during the kinetic chain exercises.

Methods: Nineteen healthy, young, active subjects volunteered to participate. The electromyographic (EMG) activity (via surface EMG) of the abdominal external oblique (EO), IO, and LM muscles on both sides and the rectus femoris and semitendinosus muscles on the dominant side was determined during rhythmical lower body twisting exercise with three lower body positions: straight leg (SL), athletic position (AP), dynamic knee extension (DE) at two exercise speeds: 150 and 90 beats per min. These were reported as % maximum voluntary contraction. Mean EO, IO, and LM muscle activities were also compared with those of common core stability exercises.

Results: IO EMG activity was significantly greater in SL than that of AP ($p < 0.05$). In contrast, LM EMG activity was significantly greater in the DE position than that of both SL and AP positions ($p < 0.05$).

Conclusion: IO muscle activity could be attenuated by the contraction of lower body extensor muscles during the standing position.

Level Of Evidence: Basic Laboratory Study, Level 3b

Keywords: abdominal internal oblique, closed kinetic chain exercise, electromyography, lumbar multifidus, movement system

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INTRODUCTION

Previous authors have advocated for training the abdominal internal oblique (IO) muscle due to its contribution to core stability through the thoracolumbar fascia, as well as being related to low back pain prevention in athletes.[1-4] For instance, elite cricket players with low back pain may not develop the IO muscle as much as their counterparts without low back pain.[3] This result is consistent with the recent finding that asymmetry of the IO muscles in adolescent soccer players is associated with low back pain.[4] The IO muscle may function as a muscle for anticipatory postural adjustment, which occurs on the contralateral side during a single arm movement.[5,6] However, anticipatory postural adjustment onset latencies were observed in those with a history of low back pain.[7,8]

Another important core muscle group is the lumbar multifidi (LM) which contribute to maintenance of extension of the trunk in the upright position against gravity. For instance, the astronaut who stayed in microgravity on the International Space Station (ISS) for six months experienced atrophy of the LM muscles.[2] LM muscle atrophy has also been identified in individuals who underwent a 60-day bed rest study compared to baseline data.[9] Furthermore, adverse structure and quality, such as a higher amount of fat infiltration in the LM muscles has been shown in subjects with chronic low back pain.[10] Interestingly, the LM muscles constitute a higher proportion of type I or slow-twitch fibers,[11] whereas in those with chronic low back pain a shift toward to type II fibers is seen, helping to produce metabolic substances during contraction.[10]

Regarding EMG studies, LM muscle activity can vary with different foot stances in a standing position. For instance, tandem stance may generate LM muscle activity with upper extremity rhythmical exercise more than that seen during double-leg stance and single-leg stance.[12] In addition, IO muscle activity may be associated with the weight-bearing leg, such as single-leg stance in the standing position compared with non-weight-bearing leg or lifting the other leg side.[12] Both IO and LM muscles can also engage during kinetic chain activities from the lower extremity to the upper extremity or vice versa in sports, such as throwing or kicking, offering stabilization of the core structures.[13] However, few of the previous studies have demonstrated both IO and LM muscle activities in kinetic chain exercise applications. Many of the intervention exercises have used an isometric contraction during plank, quadruped, or bridge positions for an extended period, such as 30-60 seconds (sec) with or without unstable conditions.[14-21] IO and LM muscle activity relative to the kinetic chain exercise manner has yet to be investigated during activities performed in a standing position. Therefore, the purpose of this study was to identify IO and LM muscle activity during weight-bearing exercises. The secondary purpose was to compare those two muscle activities in static core stability exercises. The authors hypothesized that IO and LM muscle activity would vary with lower body positions during the kinetic chain weight bearing exercises.

METHODS

Participants

Nineteen young healthy active subjects, including nine females (age: 21.4 ± 3.2 years, height: 169.4 ± 11.2 cm, weight: 70.9 ± 16.6 kg) voluntarily participated in this study. All subjects gave informed consent to the procedures as approved by the Institutional Review Board of the University prior to the examination. All subjects indicated no history of low back pain or other musculoskeletal injury in the lower body on a preliminary screening questionnaire.

Experimental procedure

For the rhythmical lower body twisting exercises the subjects stood on the customized disk board, whose top was able to freely rotate with a mild isotonic resistance in parallel with the floor and was disconnected from the frame of board. The subjects kept their feet pointing straight forward, shoulder-width apart at the edge of the disk, while standing on the board. The subjects were asked to rotate the disk for 45° in each direction: counter- and clockwise, 90°, while keeping their heels firmly on the board.

The subjects were placed in three lower body positions during exercise: 1) straight leg (SL) with knees and hips fully extended, 2) athletic position (AP) at approximately 45° of both knee and hip flexion, and 3) dynamic knee extension (DE) with back-and-forth movements between the AP and SL position. The examiner instructed the subjects to keep their lower legs under their knees in parallel with the back as much as possible during the AP position. For the DE position, the subjects extended the knee joints together from the AP position while rotating the disk board toward the target of 90°. Once their knees were extended, they flexed the knee joints together up to the AP position while counter rotating the disk board in the other direction for 90°. The cadence of the exercises was controlled by a metronome set at two speeds: 150 and 90 beats per minutes (bpm). The subjects performed all three rhythmical lower body twisting exercises while gazing at the front wall, which allowed the subjects to maintain the chest, shoulder, and face relatively stable or counter-rotated against the lower body. The subjects could also freely swing the arms with the elbow flexed while twisting the lower body (Figure 1). The subjects were able to consistently twist the lower body on the disk board for 20 sec in each exercise with a steady and constant tempo. Each subject was randomly assigned to perform the rhythmical lower body twisting exercises for three trials in each of the three positions at each of the two movement speeds to minimize motor learning or fatigue effects.

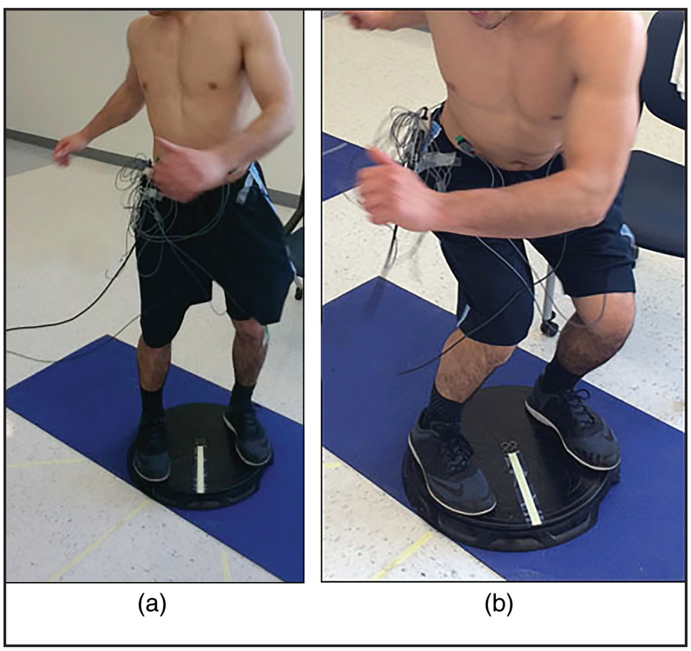

Figure 1. *Rhythmical lower body twisting exercise with the customized disk board. Subjects consistently twisted the lower body on the disk board for 20 sec with a steady and constant tempo with the straight leg (SL) position (a) and the athletic position (b). For the dynamic knee extension, subjects performed back-and-forth movements between the AP and SL position while rotating and counter-rotating the disk alternatively.*

The static core stability exercises included: 1) single-leg bridge position, in which the knee joint was flexed at 90° and the hip joint was extended at 0° in the non-dominant side (NON) while the hip and knee joints were extended at 0° in the dominant side (DOM). The subjects lifted the buttock from the floor and maintained the DOM thigh elevated in parallel with the NON thigh level while crossing their arms over the chest. 2) In the "bird-dog" position, the subjects knelt in the quadruped position and flexed the shoulder to 180° or with as much flexion as possible with the elbow extended on the NON side while extending both hip and knee joints at 0° on the DOM side. 3) In the narrow half-kneeling position, the subjects knelt on the DOM side, which kept the hip extended while the other hip and knee joints were flexed at 90° on the NON side. The subjects were asked to keep the patella of the DOM side knee in line with the heel of the NON side. All three isometric stability exercises maintained the hip joint extended at 0° on the DOM side. The subjects were asked with which side they would prefer to kick a ball and this determined their DOM side. The subjects maintained each of the stability exercises with the accurate position for 20 sec. All exercises were repeatedly implemented to measure the selected core muscle activities immediately after all the rhythmical lower body twisting exercises.

Data Management and Analyses

Surface electromyography (EMG) was utilized to measure three core muscles on both DOM and NON sides: the EO, IO, and LM muscles. Surface EMG was also utilized to measure the rectus femoris (RF) and semitendinosus (ST) muscles on the DOM side, which enabled the identification of the level of exercise intensity. To ensure that EMG activities were analyzed similarly across subjects, an electronic goniometer (Biometrics Ltd, Newport, UK) was attached to the knee on the lateral DOM side being tested.

The skin surface was prepared by vigorously cleaning with an alcohol swab to minimize skin impedance before electrode placement. Bipolar surface silver EMG electrodes (model Delsys Bagnoli-8; Delsys Inc, Natick, MA) with a bar length of 10 mm, a width of 1 mm, and a distance of 1 cm between active recording sites were used. The electrodes were placed at the center of the muscle belly in line with the muscle fibers according to previous studies. Specifically, the electrode for the EO muscle was placed over the superior to the anterior superior iliac spine (ASIS) at the level of the umbilicus.[12,16,18,22] The electrode for the IO muscle was placed at 2 cm medial and 2 cm inferior to the ASIS, aligned parallel to the inguinal ligament, and lateral border of the rectus sheath.[6,8,16,18,19,21,23] Previous articles have referred the EMG placement for the IO muscle as lower abdominals because EMG activity might be collected with transverse abdominis muscle activity as the blended site.[8,22,23] However, the activity in this study simply represented the IO muscle. The electrode for the LM muscle was placed at 2 cm lateral to the 4th/5th lumbar vertebral interspace, along a line connecting the 1st lumbar vertebrae and posterior superior iliac crest.[6,16,18,20-22] Also, the electrodes were placed at the center of the muscle belly between the anterior inferior iliac spine (AIIS) and the superior portion of the patella for the RF muscle, and between the ischial tuberosity and the medial condyle of the tibia for the ST muscle. The reference electrode was placed over the spinous process of the 4th lumbar vertebrae.

Once the electrodes were secured, maximum voluntary isometric contraction (MVIC) for each included muscle was measured by using the manual muscle-testing procedures for the normalization of EMG data. The root-mean-square (RMS) values of the EMG signals for the EO was normalized to the MVIC of the corresponding muscles in the side plank position while examiner maximally applied manual pressure over the lateral side of subject's hip.[21] For the IO, the subjects were asked to perform the abdominal drawing-in maneuver in the supine position at 45° of hip and knee joints followed by flexing the abdominal muscles evenly until the inferior angle of the scapula was barely lifted. Also, the examiner maximally applied manual pressure over both subject's shoulders together. For the LM, the subject extended the back in the prone position while the examiner maximally applied manual pressure over the back of the shoulders together. For the RF, the examiner maximally applied manual pressure over the distal and anterior portion of the lower leg with the subject seated at the edge of table with 90° of hip and knee flexion. For the ST, the examiner maximally applied manual pressure over the distal and posterior portion of the lower leg while the subject lay in the prone position with 90° of knee flexion.

Input signals of EMG activities were recorded using a data collection system (MP 150 Data Acquisition System; BIOPAC System Inc, Goleta, CA, USA) with a sampling rate of 1000 Hz, and all data was stored in a hard drive for offline analyses. The RMS for the EO, IO, LM, RF, and ST were normalized to the MVIC of the corresponding muscles as described above for further analyses.

This study analyzed normalized RMS activity of the middle 10-sec in the EO, IO, and LM muscles using a $2 \times 2 \times 3$ (side × speed × position) mixed-measures analysis of variance (ANOVA) design within subjects between the DOM and NON side crossed with two speeds and lower body positions to identify differences in each mean value during the rhythmical lower body twisting exercise. For normalized RMS activity of the RF and ST muscles, a 2×3 (speed × position) repeated-measures ANOVA design within subjects crossed with two speeds and three exercises was used to identify differences in each mean value of normalized RMS activity during the exercises. Also, a 2 x 2 x 3 (side × time × exercise) mixed-measures ANOVA design within subjects between the DOM and NON side crossed with the PRE and POST test and exercises was used to identify differences in normalized EMS activity of the EO, IO, and LM muscles during the isometric core stability exercises. Where appropriate, the simple main effect and Tukey's honestly significant different post hoc test (Tukey's HSD) were used to identify any significant difference for each normalized RMS activity. All statistical tests were performed at the 0.05 level of probability ($p < 0.05$).

RESULTS

Rectus Femoris and Semitendinosus

The typical raw EMG traces of the RF and ST muscles and IO muscles on both sides and the knee joint range of motion are shown during the rhythmical lower body twisting exercise with the SL position compared with the DE position at 150 bpm in Figure 2. Analysis of the results indicated a significant interaction in the mean values of RF EMG activities between the two speeds at 90 and 150 bpm across different three lower body positions [$F(2, 36) = 3.73$, $P = 0.034$]. Specifically, RF EMG activities were significantly higher at 150 bpm than those of 90 bpm in all the three exercises ($p < 0.01$). RF EMG activity was significantly greater in DE than that of both SL and AP for both 150 and 90 bpm (57, 34, and 43% MVIC for 150 bpm; 38, 22, and 29% MVIC for 90 bpm, respectively) (the critical value of the Tukey HSD (D_{Tukey}) = 4.51%, $p < 0.05$). Also, there was a significant difference in the mean values between SL and AP for both RF and ST 150 and 90 bpm ($p < 0.05$). ST EMG activity were significantly greater at 150 bpm than that of 90 bpm in all three exercises. ST EMG activity was significantly greater in SL than that of both AP and DE for 150 bpm (30, 24, and 24% MVIC, respectively) (D_{Tukey} = 3.02%, $p < 0.05$). In contrast, for 90 bpm there was a significant difference in ST EMG activity between SL and AP (18 and 15% MVIC, respectively) ($P < 0.05$) while no difference was observed between SL and DE.

External Oblique

Mean values and 95% confidence intervals for EO EMG activities are presented during the rhythmical lower body twisting exercises in Table 1. A within-subject (subject 3 trial) ANOVA design was used to calculate intraclass correlation coefficients (ICCs). Each of the ICCs (3,1) in different exercises is also presented in Table 1.

EO EMG activity in SL was significantly greater than that of both AP and DE, regardless of exercise speeds and sides (D_{Tukey} = 1.55%, $p < 0.05$). Also, there was a significant difference in the mean values between the AP and DE position ($p < 0.05$).

Internal Oblique

Mean values, 95% confidence intervals, ICCs (3,1) for IO EMG activities are presented during the rhythmical lower body twisting exercises in Table 1. IO EMG activity at 150 bpm was significantly greater than that of 90 bpm in all three exercises for both DOM and NON sides ($p < 0.01$). IO EMG activity was significantly greater in SL than that of both AP and DE at 150 bpm for the DOM side (D_{Tukey} = 8.32%,

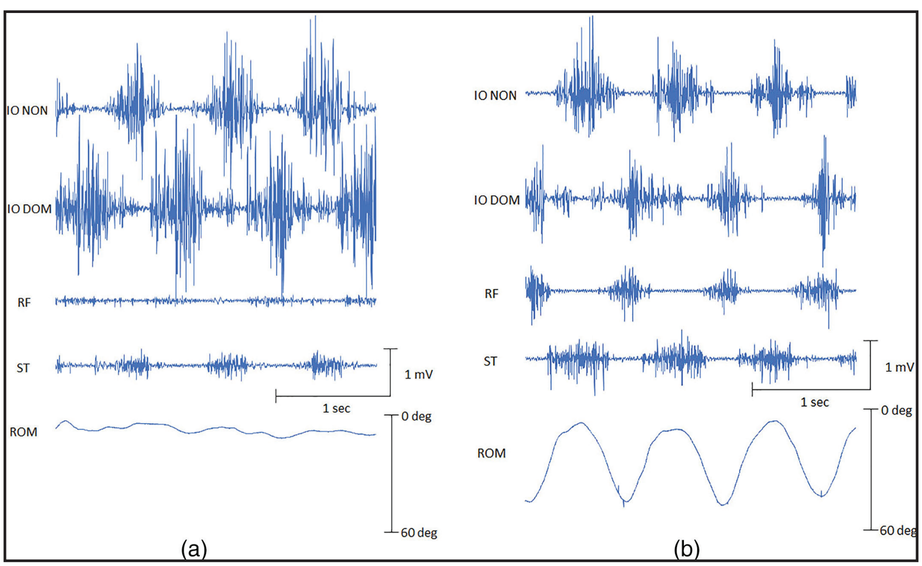

Figure 2. *Typical raw electromyographic traces of semitendinosus (ST), rectus femoris (RF) muscle activities in the dominant side, and abdominal internal oblique (IO) muscle activities on both sides: the dominant (DOM) and non-dominant (DOM) side during the rhythmical lower body twisting exercise with the straight leg (SL) position (a) and the dynamic knee extension (DE) (b). The IO muscle in the DOM side (IO DOM) was the same side as the RF muscle. For the angle trace (below), an electronic goniometer was attached to the knee on the lateral side of the arm being tested. Note the SL position decreased the amount of RF EMG activity compared with that of the DE position, which led to an increase in the amount of IO muscle activities (a). In contrast, the increased activity of the RF and ST muscles mediated the IO EMG activities in the DE position (b).*

$p < 0.05$), whereas there was a significant difference in the mean values between SL and AP at 90 bpm ($p < 0.05$). For the NON side, IO EMG activity was significantly greater in SL than that of AP at both speeds ($p < 0.05$), whereas no difference was observed between AP and DE for both speeds.

Lumbar Multifidus

Mean values, 95% confidence intervals, and ICCs (3,1) for LM EMG activities are presented during kinetic chain exercises in Table 1. LM EMG activity at 150 bpm was significantly greater than that of 90 bpm, regardless of the lower body positions and sides ($p < 0.01$). Also, LM EMG activity was significantly greater in the DE position than that of both SL and AP positions, regardless of the exercise speeds and sides ($D_{Tukey} = 3.59\%$, $p < 0.05$].

Isometric Core Stability Exercises

EO EMG activity in the DOM was significantly greater than that of NON side ($p < 0.01$). Also, EO EMG activity in the PRE test was significantly greater than that of POST test ($p < 0.01$) while no difference was observed in IO and LM EMG activities between the PRE and POST test or between the DOM and NON side. Furthermore, EO EMG activity was significantly greater in the bird-dog position than that of both the single-leg bridge and narrow half-kneeling position ($D_{Tukey} = 1.38\%$, $p < 0.05$). In contrast, IO EMG activities were significantly greater in both the single-leg bridge and bird-dog position, compared with that of the narrow half-kneeling position ($D_{Tukey} = 4.48\%$, $p < 0.05$) while no difference was observed between the single-leg bridge and bird-dog position. LM EMG activities were significantly greater in both the single-leg bridge and bird-dog position than that of the narrow half-kneeling position ($D_{Tukey} = 3.78\%$, $p < 0.05$) while no difference was observed between the single-leg bridge and bird-dog position. Mean values for EO, IO, and LM EMG activities during each of the three isometric core stability exercises are presented in Table 2.

DISCUSSION

The results of the current study demonstrated that the rhythmical lower body twisting exercises performed at two speeds with three standing positions modulated the activity of core muscles. In terms of exercise intensity, the maximum average activity of the RF muscle was 57% MVIC in the DE position at 150 bpm while the same activity at 90 bpm was 38% MVIC. In contrast, the maximum average activity of the ST muscle was 30% MVIC in the SL position at 150 bpm while it was 22% MVIC during the same exercise at 90 bpm. The use of the RF and ST muscle activities enabled the authors to describe the degree of exercise intensity during the rhythmical exercise protocol. Consequently, the exercise intensity

Table 1. *Mean EMG Activity Reported as % MVIC (95% CI's) and Intraclass Correlations [ICC (3,1)].*

		150 bpm			90 bpm		
		SL	AP	DE	SL	AP	DE
External Oblique	DOM	24 (20, 29)	19 (16, 24)	22 (19, 24)	17 (14, 20)	13 (11, 15)	15 (12, 18)
	ICC (3,1)	0.88	0.59	0.85	0.88	0.87	0.83
	NON	21 (17, 26)	18 (13, 22)	19 (14, 23)	15 (11, 19)	12 (9, 14)	14 (10, 17)
	ICC (3,1)	0.95	0.77	0.97	0.98	0.92	0.92
Internal Oblique	DOM	56 (39, 73)	44 (34, 54)	45 (35, 54)	37 (26, 47)	24 (19, 29)	30 (23, 38)
	ICC (3,1)	0.94	0.91	0.93	0.96	0.90	0.89
	NON	62 (47, 78)	45 (36, 55)	56 (43, 69)	40 (30, 50)	28 (20, 35)	33 (25, 41)
	ICC (3,1)	0.86	0.88	0.93	0.88	0.88	0.91
Lumbar Multifidus	DOM	39 (34, 45)	41 (36, 45)	51 (45, 56)	35 (30, 40)	38 (33, 44)	44 (39, 49)
	ICC (3,1)	0.96	0.46	0.79	0.89	0.69	0.83
	NON	41 (33, 49)	43 (35, 51)	48 (39, 57)	36 (28, 44)	41 (33, 48)	44 (36, 52)
	ICC (3,1)	0.93	0.78	0.92	0.98	0.94	0.89

SL = straight leg position, AP = athletic position, DE = dynamic knee extension, DOM = dominant side, NON = non-dominant side

Table 2. *Mean EMG activity reported as % MVIC (standard deviation), regardless of dominant or non-dominant side.*

	SLB	BDP	NHK
EO	11 (6)	15 (7)	10 (5)
IO	17 (12)	18 (10)	9 (4)
LM	49 (12)	46 (12)	26 (11)

SLB = single limb bridge, BDP = bird-dog position, NHK = narrow half kneeling position

implemented for 20 sec in this study can be categorized as moderate to high level.[24]

During the rhythmical lower body twisting exercise the SL position generated significantly more EO muscle activity compared with other two lower body positions. The subjects rotated the disk board for 90º (45/45 each way) using the upper body rigorously due to a minimum of momentum force generated by the lower body that rotated the disk because less activity of the RF muscle was observed. EO muscle activity is linked with upper extremity movement in the contralateral side whose force is transferred through the abdominal fascia and superficial connective tissue during the weight-bearing position.[12,25] The mean value of EO muscle activity was still 24% MVIC with the SL position during the exercise at 150 bpm, which was much less than that of IO muscle activity (56% MVIC) and LM muscle activity (39% MVIC). One possible reason for this is anticipatory trunk muscle activity that has been observed to minimize the displacement of center of mass.[6] For instance, shoulder horizontal extension and flexion in the standing position activated the EO muscle in the contralateral side as much as trunk flexion.[26] It appears that the energy and force generated by rigorous upper extremity movement during the twisting exercise with the SL position were transferred to lower extremity through the IO and LM muscles more than the EO muscles because the subjects rotated the disk board and did not stand on the stable floor. However, the augmentation of EO muscle activity during the twisting exercise significantly modified the activity in the isometric core stability exercises during the POST test compared to the PRE test.

A small amount of core muscle activity including the LM and IO muscles may be required to stabilize the segmental lumbar spine, such as 10% MVIC for rigorous activity.[13,27,28] This study considerably activated the IO muscle up to 62% MVIC during the kinetic chain exercise with the SL position. IO muscle activity has also been demonstrated to be increased in the weight-bearing position compared with the non-weightbearing position during the static standing with rhythmical upper extremity exercise.[12] This was consistent with another finding in which the IO muscle was significantly activated during the standing position versus in the sitting position while an oscillation exercise was performed in the frontal plane.[29] The rhythmical lower body twisting exercise with the SL position did not activate the RF muscle as much as the AP and DE position. The authors suggest that the IO muscle contributed to rhythmical lower body twisting to a greater degree than RF in the SL position versus the other two positions.

The activity of IO muscles can be associated with the activation of hip flexor musculature.[2] For instance, Pereira et al[30] revealed that hip flexor dynamic muscle exercises in the supine position including the criss-cross and dead-bug exercise highly activated the IO muscle. In contrast to dynamic exercises, the static exercises used in the current study in the single-leg bridge and bird-dog positions activated the IO muscle at a mild level. The narrow half-kneeling position, in which the IO muscle did not reach even 10% MVIC, appears to suggest a different strategy being used to maintain the upright half-kneeling position. A static upright position relies on the somatosensory information up to 70% of the total sensory information.[31] With this, it is feasible to suggest that the subjects kept their postural balance in the narrow half-kneeling position using peripheral information in the lower extremity instead of the core muscles. The commands excited by the higher centers for trunk muscles are projected in the medial system of descending pathways in the spinal cord.[32,33] In addition, the core muscles may not be volitionally activated in the static upright position unless the postural balance is disturbed[6,26] or when performing plank positions against gravity.[14,15,17,18,21] Consequently, the IO muscle was sparsely activated in the static core stability exercises implemented in this study.

The LM muscles were significantly activated in the DE position more than that of the SL and AP positions during the rhythmical lower body twisting exercise. LM muscle activity may have compensated for IO muscle activity during the rhythmical lower body twisting exercise because the IO is attached to the thoracolumbar fascia[13] and the LM are covered by it.[13] Furthermore, LM muscle activity might be associated with RF muscle activity as part of extensor muscles in the weight-bearing position. But the narrow half-kneeling position decreased LM muscle activity along with a small amount of IO muscle activity. This suggests that the subjects kept their upright half kneeling balance using peripheral information from hip and thigh muscles rather than core stability muscles.

Clinically, these results provided evidence that IO muscle activity was greater during the rhythmical lower body twisting exercises than during isometric core stability exercises, which was confirmed by the PRE and POST test. The findings of this study may be applied to those who need to generate rotational stability on their feet in sports. This is because most athletes who perform closed kinetic chain activity, such as throwing or serving a ball, are required for a lower body rotation leading to energy transfer into their upper body or vice versa, such as kicking a ball.[13]

Limitations

This study included a sample delimited to young healthy active subjects. Thus, this study may limit the generalization of the findings regarding age, gender, and other cohort groups. The kinetic chain exercise implemented in this study may limit the understanding of the role of core stability muscles in sports specificities. This study used surface EMG recordings instead of a fine-wire intramuscular electrode to represent the EMG of the LM in these subjects, which could allow crosstalk from adjacent muscle activity including the erector spinae muscles.

CONCLUSION

This study investigated muscular activation during a novel mode of lower body twisting (kinetic chain) exercise performed on a customized rotation board. The findings of this study suggest that the IO muscle appears to be modulated with lower extremity extensor muscles in the weight-bearing position. Further studies are warranted to investigate the effect of kinetic chain exercise on the activity of the IO and LM muscle for injury prevention exercise programs.

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